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CHAOS ON THE COMMONS: CONSIDERING THE IMPLICATIONS OF NONEQUILIBRIUM THEORY FOR COMMON PROPERTY RESEARCH

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INTRODUCTION

Conventional views of change in social systems have typically focused on incremental or equilibrium models wherein change is based upon relatively slow adaptation when only minor adjustments are made to existing structures and institutional arrangements. Traditional conceptions of policy processes and decision making, have, likewise, been based on assumptions of incremental change from which minor adjustments lead to the maintenance of the existing order, stability or equilibrium. However, this view of change, with its implicit control orientation, fails to encompass the entirety or complexity of the developmental processes at work in systems experiencing dramatic or wholesale change These more dynamic occasions, when systems take on new behaviors, patterns of interactions, and structure, are typified by a high degree of uncertainty and unpredictability as to the outcomes of the systemic changes.

Over the past three decades, an emergent paradigm in the natural sciences has begun presenting an expanded view of the evolutionary processes in systems which welcomes instability and disorder as the precursor to the development of entirely novel forms of behavior, patterns of interaction, and structure. This paradigm, deriving from investigations of the dynamics of nonlinear systems[1], has added new insights into the study of complexity in natural systems. An emerging theory from these discoveries in the natural sciences, nonequilibrium theory, presents a view of the processes of change in which instability, disorder, and unpredictability serve as central features in the development of new forms of organization and complexity.[2] Nonequilibrium theory can provide insights into the nature of qualitative changes in systems--those instances during which existing structures break down and reconverge into genuinely novel forms of organized complexity. Most recently, scholars and researchers across the social sciences have begun to apply tenets of nonequilibrium theory to the study of social phenomena ranging from economics to urban development and planning, policy processes, and public administration.

This article explores the theoretical implications of nonequilibrium concepts for the study of common property resource (CPR) systems by presenting nonequilibrium theory as one model for understanding and analyzing discontinuous change in systems and structures relevant to CPR systems. One such system, the Navajo Indian Irrigation Project (NIIP), was selected to serve as a case study for this examination The NIIP is a massive irrigation/agricultural economic development project which is located in the United States southwestern desert region within the Navajo Indian Nation Reservation. The Navajo reservation occupies the northwest corner of the state of New Mexico and the northeast corner of the state of Arizona, however the NIIP is confined geographically to the state of New Mexico. The NIIP will be considered as an illustrative case which demonstrates the complementarity of nonequilibrium theory to incremental models of change while it provides a more complete view of the entirety of evolutionary processes relevant to CPR systems. After outlining the basic elements of nonequilibrium theory and presenting the developmental history and current status of the NIIP, this paper examines the NIIP from a nonequilibrium conceptual perspective. In assessing the elements of nonequilibrium theory which are efficacious in explaining the development and contemporary state of the NIIP, this work posits that a combination of traditional and nonequilibrium approaches is required to fully explicate the evolution of this CPR system. Finally, the paper concludes with some observations on the implications of nonequilibrium theory for future common property systems research.

NEW SCIENCE, NEW VISIONS OF HUMAN SYSTEMS: NONEQUILIBRIUM THEORY

While scientists across the natural sciences have contributed substantively to the development of nonequilibrium theory, it is Nobel Laureate chemist Ilya Prigogine who is generally recognized as nonequilibrium theory's most influential scholar. The term nonequilibrium theory was derived from Prigogine's work with complex chemical compounds in "far-from-thermodynamic-equilibrium." From a thermodynamic perspective, the degree of complexity a system exhibits is the determinant of the amount of work or activity the system can perform. Prigogine referred to complex systems in this nonequilibrium condition as dissipative structures. "Dissipative structures consist of a variety of subsystems that interact in a nonlinear fashion. These structures are subject to a large range of possible interactions both internally and with their external environments"[3]

Prigogine noted that under experimental conditions complex compounds exhibited predictable behavior for certain periods of time, but at other times random fluctuations, either external or internal to the system amplified the nonlinear interactions of the system At the point when nonlinear interactions dominate, the system may extend beyond the boundaries of stability becoming unstable Further interactions may push the system to a critical point of instability referred to as a "bifurcation point." At the bifurcation point, the symmetry of the existing structure breaks down initiating a system state dominated by randomness and unpredictability. In the dissipative structure, the symmetry of the previous structure is destroyed and the behavior of its component elements becomes devoid of pattern or, its behavior becomes chaotic. However, this chaos actually represents the continuous production of novelty with the uncertainty and indeterminacy of this chaotic interlude affording the dissipative structure an opportunity to explore a variety of evolutionary possibilities.

Until some element of the pre-existing structure attracts sufficient energy to generate a new emergent configuration, the system continues its stream of chaotic and unstable behavior Ultimately, when a new structural regime finally stabilizes the system, the new dissipative structure will characteristically reveal an increased level of organization relative to the previous structure. "A new dissipative structure is also typically more complex, or capable of more activity and work, when compared to its previous state. This is due to its increased capacity to attract, utilize, and organize available energy for its creation and maintenance."[4] Prigogine referred to this potential for more complex and highly organized structures to evolve following a symmetry break in a pre-existing dissipative structure as "self-organization." Without self-organizing behavior, the result of a symmetry break in a system would be continuous random or chaotic behavior.

It is important to note that it is impossible to predict the evolutionary pathway the system will follow at the bifurcation point. Therefore, it is also impossible to predict the exact nature of the resulting new system configuration. Since dissipative structures reveal deterministic behavior for some periods of time and random fluctuations with nonlinear interactions at others, the mathematical foundation of nonequilibrium theory includes elements of both determinism and chance. While the cumulative history of the system's structure determines its evolution, the unpredictability of nonlinear interactions provides the "systems considerable opportunity to explore a variety of possible futures prior to stabilizing at a new level of complexity "[5]

When extended beyond the limits of their own stability, dissipative structures reach transition points that may generate novel new configurations within the system. The characteristic pattern by which processes were linked within the system, relative to the previous structure, may be altered significantly. The new formations are "contingent upon a high degree of cooperation among the constituent elements. This cooperation represents the self-organizing properties of a system, and is exemplified by the creation of a dissipative structure."[6] Even though the system might have been pushed to the symmetry break by external factors, internal self organizing forces appear to be responsible for the eventual creation of the novel, more complex and adaptive reorderings. With its capacity for self organization and the generation of novel complexities, the natural realm protects itself from being overcome by entropy and from falling into decay. While the model of change descriptive of dissipative structures does not negate incremental evolution by adaptive selection, nonequilibrium theory, rather, reveals that both adaptive evolution and transformational change are important features, at various times, in the development of complex systems.

Laurent Dobuzinskis[7] has observed that increased interest in systems theory; both traditional systems theory and the newer nonequilibrium theory, over the past twenty to thirty years, has resulted in the development of two distinct, but conflicting, systems-theoretic visions. In the traditional view, systems are designed to emphasize control, stability, homeostasis and equilibrium as they operate within the context of a deterministic universe. Expressing the modern[8] "idea that knowledge is power--the power to impose a preconceived (i.e., rational) order on nature and society,"[9] these systems models concentrate on commonly accepted notions of corrective feedback, stability, control, and rational planning and decision making.

The emergent alternative conception, in contrast, produces systems models which emphasize the evolutionary dynamics, chaotic fluctuations and spontaneous adjustments of systems operating in the context of a deterministic, yet entirely unpredictable universe. This universe, itself composed of culturally and individually constructed worlds, must be examined with "alternative methodologies that view homeostatic strategies as being dysfunctional in complex open systems capable of restructuring their operations."[10] This transition is signaling a move away from traditional reliance upon technocratic certainties to a recognition that societal actors at every level have considerable and important insights to contribute to the policy process. These newer models point to the "paradoxical, i.e., 'tangled' or 'nested' character of hierarchical relationships that develop between policy analysts and policy makers, one the one hand, and a multitude of social agents or groups on the other."[11]

It has become increasingly more difficult for social scientists to maintain the limited perspective of the controlled equilibrium system model when dealing with the complexities of contemporary social systems. For researchers and analysts searching for novel approaches for understanding the combination of forces pulling a system in several directions at once, nonequilibrium theory offers novel new analytical perspectives. Problems, which until recently had been ignored or simplified beyond recognition because they involved complex and unpredictable relationships or random variations, can now be studied using these new theoretical innovations. Nonequilibrium theory suggests a rethinking of the value of reductionism in scientific research. "Reductionism is a result of Newtonian linear constructs premised on the identification of a system's most discrete elements."[12] This approach assumes that the behavior of the larger system can be predicted by examining and projecting the trajectories of the most discrete elements or entities. Nonequilibrium theory devalues reductionism, since change resulting from the activity of nonlinear systems is unpredictable. Knowledge of all the discrete elements, no matter how small, affords little direction as to the constitution of future states of the system. Nonequilibrium research leads to a more holistic and integrative research approach than has been the case in traditional models.

Common property resource scholar Elinor Ostrom has acknowledged the importance of studying the temporal behavior of multi-level social systems, such as CPR systems, within their operating contexts.[13] It is important to note that these new nonequilibrium theoretical models are concerned with phenomena which are highly dependent upon initial conditions. The slightest changes in initial conditions produce completely different systems over time. "In other words, there is no such thing as a <u>ceteris paribus</u> or context-independent situation"[14] Moreover, these phenomena are characterized by their irreversibility. In striking contrast to the established (Newtonian) control paradigm, nonequilibrium theory is concerned with transformations in systems which cannot be reversed.

Across disciplines as diverse as business[15], management[16], urban planning[17], policy systems analysis[18], political science[19], public administration[20], and sociology[21], there is an increasing interest in and concentration of intellectual effort upon the non-linear aspects of social systems. In 1990, CPR scholar Estellie Smith explored fisheries as nonlinear, dynamic systems.[22] From a nonequilibrium perspective, the environment of a CPR system may be seen as a mosaic of organizations at varying stages in their evolution. While some organizations may be declining into less energetic, lest vital states, others may be self-regulating by incremental adjustment. Other systems, within the same environment, may be experiencing extreme instabilities which may lead to symmetry breaks and novel reconfigurations.

Although a symmetry break with a novel reconfiguration may be an infrequent event in the history of an individual CPR system, in an increasingly interactive and complicated environment, symmetry-breaking behavior may be occurring within a variety of the CPR's subsystems. "What appears to typify modern complexity is the relatively frequent occurrence of critical fluctuations among many subsystems, resulting in an increasing array of qualitative change throughout the entire system."[23] It is this understanding that makes nonequilibrium theory so appealing for CPR research. The variety of interactions, within and across the boundaries of these systems, provides considerable opportunity for the generation of instability among a variety of subsystems. The seemingly unstable nature of open societies, the intrusion of politics, and the decisions and actions of a variety of internal and external actors may all contribute to significant environmental change. Incremental efforts to maintain equilibrium in a rapidly changing environment can be extremely dysfunctional. A lack of coordination between an internal organization and the environment inhibits the system's capacity to import sufficient energy from its environment for sustenance. Incremental adjustment in a rapidly changing environment may substantively decrease the system's alignment with its environment.

Adapting to the exigencies of an inconsistent, ever evolving environmental context has become a requisite behavior for survival in the developmental history of the Navajo Indian Irrigation Project. The

NIIP is a long enduring, self-organizing[24], increasingly self-governing, highly complex common property resource system which clearly illustrates many of nonequilibrium theory concepts which have been presented here More specifically, this work argues that, in fact, any understanding of the development and contemporary status of the NIIP which does not include nonequilibrium analysis of the systems's development results in an impoverished understanding of the project's evolution. After a brief overview of the historical development and current status of the NIIP, this paper will present a nonequilibrium exploration of the nonlinear temporal behavior exhibited by this highly dynamic CPR system.

THE NAVAJO INDIAN IRRIGATION PROJECT: AN OVERVIEW

The Navajo Indian Irrigation Project was originally envisioned as a 110,630 acres irrigation project to be developed by the United States federal government for the Navajo Indian Nation.[25] The U.S. Congress agreed to build the NIIP in 1962, as a confirmation of the negotiation and agreement among the Navajo Nation, the state of New Mexico and the federal government The Navajo Nation agreed to share its water rights to the San Juan River with other water users and also agreed to allow the trans-basin diversion necessary to facilitate the companion San Juan/Chama Diversion[26] in exchange for which, the U.S. government agreed to develop the NIIP. The NIIP was also considered to be a partial satisfaction of the earlier Treaty of 1868, between the Navajo Nation and the United States.

The NIIP was authorized by Acts of Congress approved April 11, 1956 (70 Stat. 105); June 13, 1962 (76 Stat. 96); and August 4, 1977 (91 Stat. 565). The pertinent part of the 1962 Act (P.L. 87-483) authorizes the "Secretary of the Interior to construct, operate and maintain the Navajo Indian Irrigation Project and the initial stage of the San Juan-Chama project as participating projects of the Colorado River storage project, and for other purposes."[27]

According to the 1962 legislation, the NIIP as a federal reclamation project on the Navajo Reservation, was to bring economic development to the Navajo Tribe in the form of 18,000 jobs (at that time one-fifth of the reservation population) on irrigated family farms and related enterprises and was to be completed in 14 years. In hearings testimony presented to the Subcommittee on Irrigation and

Reclamation, Bureau of Reclamation personnel stated the benefit cost ratio of the NIIP to be 1.31 to 1 which recommended the approval of the project to construct irrigation and service works and establish approximately one thousand 125-acre subsistence family farms on Navajo reservation lands.[28] The net irrigated acreage was to ultimately reach 110,630 acres irrigated by an annual diversion of water from the Navajo Dam of 508,000 acre feet. The project works were to include a main canal projected to be 152.6 miles long at completion with lateral distribution facilities, pumping stations and power generating facilities sufficient to maintain the system. Estimated cost of completing the project was $134,359,100 and it was scheduled to have been complete in 1976.[29] The Bureau of Indian Affairs was initially assigned overall responsibility for the NIIP including the acquisition of funds to complete the project and the operation, maintenance and replacement of the constructed facilities. The Bureau of Reclamation was assigned responsibility for the planning, design and construction of the NIIP.

Thirty three years and $450 million dollars later, the NIIP is barely recognizable as the project Congress approved in 1962. As of 1995, the project stands at approximately 60% of completion with just over 60,000 acres irrigated and under cultivation. (In 1976, the year the project was originally scheduled to be completed, irrigation water finally reached the first 10,000 acre "block" to be cultivated in the project). Instead of subsistence family homesteads, today, the NIIP is a sophisticated agri-business tribal enterprise operating under the direct management of the Navajo Agricultural Products Industry (NAPI), which was established in 1970 by the Navajo Tribal Government's Economic Development Commission.[30] While NIIP/NAPI currently employs some 400 full-time and 1500 seasonal employees (99% of which are Navajos), the 18,000 jobs projected at the inception of the project has never been realized. However, at present, NAPI has developed four major operations on the NIIP. These operations include industrial parks, an agricultural and research testing laboratory, custom livestock feeding facilities and massive farming complexes which produce operating revenues in excess of $37 million dollars annually. NAPI continues the economic growth effort by establishing joint ventures with interested agricultural entities and these joint operating agreements will increase opportunities for Navajos seeking employment. Despite having to endure chronic and perpetual under-funding, tumultuous political and environmental dynamics and the ravages of poor planning and episodes of (admittedly) bad management NIIP/NAPI is, today, a CPR system which has "transformed" itself in response to overwhelming sub-system instability How and why this transformation has occurred, which nonequilibrium processes would appear particularly useful in describing the interactions at work in the evolution of this CPR, and the behavior of this system over time will be the focus of the next section.

A NONEQUILIBRIUM PERSPECTIVE ON THE NIIP

In the Navajo language, the NIIP is called the Dáá'ák'eh Nitsaa or "The Large Farm." This understanding is reflective of the metamorphosis which has occurred in the structure and behavior of this project since its inception. As was noted earlier, nonequilibrium systems theory posits that systems pushed past the limits of their own stability reach transition points which generate new configurations of the system. The effects of these transitions are cumulative and over the life of the system, may, with successive iterations, eventually result in the type of transformation observable in the NIIP. A close examination of the development of the NIIP reveals a number of factors at work which can be understood using nonequilibrium theoretical conceptualizations. The four examples which follow are indicative of these conceptualizations.

1. Sensitive Dependence On Initial Conditions. New nonequilibrium theoretical models are concerned with phenomena which are highly dependent upon initial conditions. Minute changes in initial conditions can produce remarkably different systems over time. It also makes a context independent system an impossibility. In the case of the NIIP, the political, economic and cultural context within which the project was initiated clearly provided a less than conducive set of initial conditions. First, the project was initiated based on the pervasive assumption that the Navajo would operate individual, subsistence level, family farms on the NIIP [31] This unchallenged assumption ignored the fact that the Navajo had never been farmers, they had historically been livestock herders, and that this fundamentally illiterate population had no experience or training in irrigated agricultural farming. (Moreover, there was little evidence to suggest they wanted to learn to be family farmers). Secondly, The Navajo essentially traded

their rights to water from the San Juan River (for the San Juan/Chama diversion) to acquire the project works for the NIIP Unfortunately, political support for the two projects was not equitable While the diversion project was fully funded from inception and finished precisely on schedule five years later, the NIIP was derailed by the Interior Department immediately after passage of the authorizing legislation. Five months after the NIIP's authorization, the Bureau of Reclamation's first act in administering the project was to call for its complete reconsideration, including the development of a new plan to "optimize the net benefits to the Indians from the water allotted to the Navajo Indian Irrigation Project."[32] Thirdly, the unusual funding arrangement provided for the NIIP in its authorizing legislation has created chronic under-funding throughout the project's history. The Bureau of Indian Affairs (BIA) was charged with responsibility for obtaining funding for the NIIP, funding it would then pass through to the Bureau of Reclamation. One influential Congressman, unhappy with Congressional acknowledgement of the Navajo's water rights is said to have demanded the peculiar provision since " the BIA has considerably less influence in Congress than does the Bureau of Reclamation."[33] Thus, funding delays and cutbacks would be easy to accomplish. And so they were. Construction, development and training funds were reduced, withheld, reconsidered and delayed.

By 1964, only two years after the project was authorized, BIA officials in Washington were already discussing major changes in the NIIP plan. The pernicious effects of unexamined assumptions about the Navajo's capacity or interest in learning irrigated agricultural techniques, the vagaries of internal and external politics and pervasive under-funding were exacting heavy tolls. It became apparent that the NIIP plan, as it was first envisioned, was unworkable and it was becoming clear to Navajo and federal officials that the plan would require wholesale, dramatic, structural change. In November of 1964, BIA officials in New Mexico held the first meetings at which the conversion from the family farm concept to a Tribal Enterprise development was considered.[34]

2. Irreversibility. Nonequilibrium theory is also concerned with the irreversibility of transformations in systems. One profound insight that policy analysts gain from the study of nonequilibrium systems is that social dynamics are no more (and probably less) reversible than

thermodynamics. In our conventional understanding of "planning" time runs backwards from rationally determined objectives back to the present, as if the social fabric can be folded and unfolded without effort. However, we know that historical processes follow a one way path that almost always deviates from the pre-determined end states for which planners aim.[35]

Once the Navajo had traded away their water rights to acquire the United States Federal Government's financial assistance with developing the NIIP, and the water was actually diverted to the San Juan/Chama project, that quantity of water was gone forever and the Navajo's Nation's situation was permanently altered. Life on the reservation, the eventual configuration of the NIIP, and, in a larger sense, the history of the Navajo Reservation was inexorably changed. Once this change had occurred, it was irreversible. In a similar manner, any major substantive changes made to the NIIP project, given the very large scale and tremendous expense involved with making significant change in a project of this scale, made changes virtually irreversible in every practical sense. For instance, once the change to a commercial agriculture enterprise from the family farm model was initiated, any possibility for returning to the family farming model was negated. When the Bureau of Reclamation decided in 1965 to reduce the size of the main irrigation canal capacity, the remainder of the system had no viable choice except to adapt to survive. Once these types of wholesale changes have reconfigured the entire system, the effects cannot be reversed because the system has qualitatively changed.

Intuitively, we understand the old adage that a person cannot step twice into the same river. Nonequilibrium theory incorporates this intuition into the study of change in human systems and maintains that the cumulative history of the systems's structure determines its evolution. As Ilya Prigogine has observed, the arrow of time points only in one direction.[36]

3. <u>The "tangled," "nested" nature of nonequilibrium systems</u>. One of the elements Ostrom has identified as indicative of long running (i.e., adaptive) CPR systems is a tangled, nested, or multi-layer hierarchical organizational structure.[37] Nonequilibrium theory models point to the nested or tangled character of hierarchical relationships which develop within systems, but in addition, these newer models consider these systems within a larger external context which is often as tangled as the internal structure.

Nonequilibrium theory holds that the relationships that develop between policy analysts and policy makers along with the multitude of social agents and groups which act upon or within a system must be included in any understanding of an evolving system. In addition, these nested systems of complicated internal relationships are usually situated in equally tangled webs of governmental agency, intergovernmental, interjurisdictional and sometimes international connections. The NIIP is certainly illustrative of this point.

The NIIP is presently governed by the Navajo Agricultural Products Industry, established in 1970 to supervise the day-to-day operations of the project on the reservation. NAPI is an administrative board comprised of members nominated by the Tribal Council (the representative governmental authority which is composed of elected delegates from the eighty-eight "chapters" of the Navajo local government structure), and approved by the Council's Economic Development Commission. In addition to representing the Navajo people's interests on the Reservation, the Tribal Council also serves as the tribe's liaison to the outside world of other governmental entities. Just a cursory list of some of the subsystems within which the NIIP/NAPI operates or with which it maintains relationships overwhelms comprehension. Simply by virtue of its geographic location, the Navajo nation maintains close working relationships with two state governments along with multiple county and municipal jurisdictions. As signatories to various regional water compacts, agreements, and treaties the Tribal Council, and by extension the NIIP, operates within arrangements with up to ten other state governments and numerous other regional tribal authorities and governments.[38] In addition, the United States government through the Department of the Interior, maintains extensive relationships with the Navajo Nation and the NIIP through the Bureau of Reclamation and Bureau of Indian Affairs.

While these governmental interconnections are significant to the behavior of the NIIP, they only begin to hint at the larger network of subsystems impacting this complex entity. A complete listing of all the disparate subsystem connections at work on the NIIP is probably impossible to collect and would certainly be too extensive to present here, but a few of the most salient ones can be considered illustrative. Some of the more crucial (and obvious) subsystems include: vendors, suppliers, lessees and customers, all operating within still larger market conditions and economic system forces, transportation and energy supply subsystems, supporting service industries, and infrastructure subsystems.

The operating dynamics of a nonequilibrium system functioning at this level of complexity suggests a rethinking of the value of reductionism in CPR research, and illustrates instead, the value of a more holistic approach to system apprehension. The underlying assumption of Newtonian scientific reductionism is that the behavior of large systems can be predicted by examining the system's smallest, most discrete elements. Nonequilibrium theory devalues this reductionism because the potential for change, within and among this many complex subsystems is completely unpredictable as to its specific nature, and therefore, knowledge of all the microscopic elements affords little direction as to the constitution of future system states. Nonequilibrium research may ultimately lead to a more holistic and integrative research approach than is apparent in much of current CPR research.

4. Dissipative Structure and Self-Organizing Behavior. Prigogine referred to complex systems in nonequilibrium condition as dissipative structures which consist of a variety of interacting subsystems subject to a large range of possible interactions both internally and with their external environments. Pushed past the boundaries of stability, the behavior of the system may become unstable as the system endeavors to explore a variety of evolutionary possibilities. This unstable behavior will continue until a new structural regime, based on some pre-existing element of the former structure, can stabilize the system. While the cumulative history of the system will determine its evolution, it is impossible to predict the evolutionary pathway the system might follow at its bifurcation point. The new formations are "contingent upon a high degree of cooperation among the constituent elements. This cooperation represents the self-organizing properties of a system, and is exemplified by the creation of a dissipative structure."[39]

As has been illustrated in the preceding discussion, the NIIP clearly fits Prigogine's description of a dissipative system. While there are myriads of potential examples which could be used to illustrate the NIIP's history of symmetry breaking and self-organizing behavior, the following are indicative of the system's capacity for restructuring its operations in the context of nonequilibrium behavior among its subsystems.

One of the earliest adaptations the NIIP was forced to make was the transition from the early "family subsistence farm" concept to the agri-business enterprise model. While there were any number of subsystem interactions which contributed to the ultimate conversion (including a cultural aversion within the user population subsystem to the notion of subsistence farming, inadequate development, training and construction funding, political unpopularity, etc.), it may have been nonequilibrium behavior in the larger economic system which was most responsible for the reconfiguration. By the 1970's family farms did not compare favorably, economically, with corporate farms. The estimate of a profitable minimum farm size had more than doubled since the 1950s. In 1972, 320 acres was considered to be a minimum sized economic unit.[40] This per-farm acreage requirement would have reduced the total number of Navajo families to be aided by the project under the family-farm arrangement from over 1,000 to 345. Larger farms which could take advantage of greater efficiencies and economies of scale would reduce the figure even further. Thus, one of the most attractive features of the family farm concept, that they would maximize employment, diminished with increases in farm size. By the early 1970s, "a tribal enterprise running a corporate farm appeared to be the way to organize the NIIP."[41] However, an enterprise of that scope would obviously require an administrative organization capable of directing and managing operations. Despite the fact that the Navajo had had little experience in corporate management, agricultural or otherwise, they capitalized on the opportunity. A fledgling organization, the Navajo Agricultural Products Industry, created by the tribe in 1970 and initially charged with training individual Navajo farmers to conduct irrigated agriculture would no longer be necessary under this new structure. However, if NAPI could be transformed into a suitable administrative entity, it could provide the direction and supervision which would be required to complete the system's transformation. While it was certainly not without initial difficulties, the transformation did take place and since 1986 NAPI has been producing annual profits in excess of $2 million.[42] Today the NAPI stands as an exemplary example of the progress the Navajo have made in their efforts at self-management of the NIIP. It also serves as an instructive example of the behavior of a dissipative, self-organizing structure.

The history of the NIIP is replete with numerous examples of just this type of dissipative structure, self-organizing behavior as a reaction to changes in various subsystems. In 1974, the Bureau of Reclamation, in consultation with the BIA and the Navajo tribe decided to convert the NIIP from the gravity flow irrigation system initially designed, to a center pivot all-sprinkler irrigation project. While this change completely altered the structural elements of the projects, the system adapted to this wholesale change and continues to thrive.

Most recently, it has been interesting to note the spontaneous development of a number of educational opportunities and training facilities, designed particularly for NAPI, by various suppliers of the project's equipment and material. As the NIIP has become larger, more complex and economically successful, the supplier subsystems have begun to react in facilitating NAPI's training and educational agenda. John Deere equipment company, for example, not only provides on-sight training for the heavy equipment it supplies NAPI, but more importantly, has facilitated partnerships with both the University of Illinois and Colorado University to educate Navajo high school students in agricultural research.[43] These kinds of unpredictable changes in the patterns of interactions among subsystems are, once again, reflective of the dissipative nature of nonequilibrium systems.

Given the NIIP's history of instability as a result of policy and programmatic changes, facilities design changes, political priority shifts, chronic under-funding and the constant threat of early termination by the United States government, its facility to adapt to systemic change has undoubtedly been instrumental in the project's survival. That it has not only survived, but is now a thriving, successful and profitable enterprise lends credence to the proposition from nonequilibrium theory that the process of reformulation, or self-organization may be expedited by a pre-existing responsiveness to change.

More importantly, however, it would seem that in this case, employee commitment to the organizational renewal cannot be overemphasized. Kiel has observed that the level of employee commitment to organizational renewal will determine the duration of the period of chaos prior to effective reorganization in public administrative organizations.[44] The NIIP seems to illustrate that participant commitment to the changes necessary to ensure the system's survival and health expedites the self-organizing properties. This level of commitment may be seen as an attracting entity that captures resources for the purposes of system reformulation. Without this form of clear attracting entity or source, unpredictable behavior might continue for extended periods of time.[45] The NIIP has exhibited a singular facility reorganize itself into new structural regimes which have achieved what Erich Jantsch has called the confirmation of its own novelty.[46]

CONCLUSION

Traditional CPR research scholarship holds that common-pool resources share two characteristics. First, that the resource is so large that it is costly (but not impossible) to exclude potential beneficiaries from obtaining its use. Second, the supply is limited; consumption by one user reduces its availability to others.[47] Clearly, the NIIP fits this basic definition. The NIIP also conforms to Ostrom's more elaborate CPR typology which identifies several essential elements common to long enduring, self-organized and self-governed CPR's. These elements include: clearly defined boundaries, congruence between appropriation and provision rules and local conditions, collective-choice arrangements, monitoring, graduated sanctions, conflict-resolution mechanisms and that the enterprise has a "nested" character. After an examination of the NIIP from a nonequilibrium conceptual perspective, however, the analytical perspective of conventional CPR scholarship seems sparse, limited and unlikely to engage the full complexity of this remarkable social system. While collective choice arguments and institutional analyses, are helpful in clarifying many aspects of the behavior of CPR regimes, they neglect the contextual, temporal, dynamic aspects of change in ever changing systems. Amidst the static rational choice behavior vs. structure orientation which pervades much of mainstream CPR research, an acceptance of the ontological and epistemological shifts which have taken place across other disciplines, could enrich and expand CPR scholarship to include examinations of the puzzling combination of forces pulling CPR systems in several directions at once.

While candor demands the admission that the methodological progress which permits sophisticated nonequilibrium analysis of physical systems has not yet resulted in tools which translate well for social system research, (in fact, social analysis conducted using the transferred methodologies presently available from the physical sciences generally breaks down into unintelligibility), much effort and research is underway which should correct this deficiency relatively quickly.[48] Until then, the value of these concepts as useful metaphors, policy models and perceptual lenses is not diminished. The implications of this paradigmatic vision for the understanding of social problems in general and complex systems in particular are very compelling.

As a research tool, nonequilibrium theory might afford students of common property systems a framework for understanding genuinely discontinuous change processes in highly complex systems. Guy Engelen made the following observation regarding the value of nonequilibrium theory to social science researchers:

> The importance of this all for the social scientist is that he how has a scientific base on which to explain systems that evolve in time and space to a higher order and more complexity resulting from the effects of fluctuations from within or outside the system. This observation is not new for the social scientist but the tool is.[49]

The potential value of nonequilibrium theory to common property research is, then, signaled by the fact that "this observation is not new" either for the actors involved in common property resource systems or for the scholars.[50]

Finally, given the historically uneasy relationship between CPR systems and bureaucratic administrations, nonequilibrium theory development within the discipline of public administration could possibly signal an opportunity for a more constructive dialogue between the two scholarships. Although common property resource systems vary in institutional arrangements, few, if any, exist in isolation from governmental entities and relationships with public administrative organizations. The nested character, or quality of these relationships suggests that radical changes in research directions and initiatives in public administration theory are likely to have significant implications for CPR systems and CPR research Contemporary public administration research is increasingly adopting a language which captures many of the principle elements of the dynamics of nonequilibrium systems. Its present concern with "flexible structures" and "self-designing systems" appears to reflect a new understanding and appreciation of the unique aspects of highly complex systems.

Perhaps this trend also suggests a rare opportunity for the development of a shared intellectual endeavor, linking CPR scholarship and public administration scholarship, through the adaptation of a nonequilibrium understanding of the change process in complex systems such as common property regimes. This opportunity may provide a set of concepts and representations which could unify the concerns of analysts, on both sides, who might be attempting to evaluate the merits of various governing instruments, societal structures and legal issues around common property systems. Hopefully, it can provide a more comprehensive means of understanding the multifaceted problems we share in attempting to establish and protect common property systems throughout the world.

NOTES

1. In a linear system, relationships between cause and effect are proportionate and the mathematical relationship between variables is stable. In nonlinear systems, the relationships between variables are dynamic--the relationship between cause and effect is not proportionate.

2. L. Douglas Kiel, "Nonequilibrium Theory and Its Implications for Public Administration," Public Administration Review, Volume 49, No.6, (November/December 1989), pp. 544-551. Kiel has been singularly instrumental in articulating the theoretical constructs of nonequilibrium theory as they are applicable to public administration as a discipline. See also "Budgets As Dynamic Systems: Time, Chance, Variation and Budgetary Heuristics," Journal of Public Administration Research and Theory, Volume 2, No. 2, (1992), pp. 139-156 and "Nonlinear Dynamical Analysis: Assessing Systems Concepts In A Government Agency," Public Administration Review, Volume 53, No. 2, (March/April 1993), pp. 143-153. Kiel's work provided the model for this study and much of the commentary on nonequilibrium theory is drawn substantively from his 1989 article.

3. Kiel, "Nonequilibrium Theory," p. 545.

4. Ibid., p. 545.

5. Idem

6. Ibid., p. 546.

7. Laurent Dobuzinskis, "Modernist and Postmodernist Metaphors of the Policy Process: Control and Stability vs. Chaos and Reflexive Understanding," Policy Sciences, Volume 25, No. 4, (November 1992), pp. 353-380.

8. Dobuzinskis explained that the use of the term "modern," as it is used here, refers to the world view first articulated by Bacon and Descartes. The central tenet of this view "is the capacity of human reason, aided by empirical observation to establish a basis for intersubjective agreement concerning the universal laws governing objective reality" (1992, p. 375).

9. Ibid., p. 356.

10. Ibid., p. 357.

11. Ibid., p. 356.

12. Kiel, "Nonequilibrium Theory," p. 549.

13. Elinor Ostrom, "How Inexorable is the 'Tragedy of the Commons?': Institutional Arrangements for Changing the Structure of Social Dilemmas," Distinguished Faculty Research Lecture, Indiana University, 1986, pp. 19-20.

14. Dobuzinskis, "Modernist and Postmodernist Metaphors," p. 363.

15. H. Richard Priesmeyer, Organizations and Chaos: Defining the Methods of Nonlinear Management (Westport, CT: Quorum Books, 1992); Ralph D. Stacey, Managing Chaos: Dynamic Business Strategies in an Unpredictable World (London: Kogen Page Ltd., 1992).

16. Margaret Wheatley, Leadership and the New Science: Learning About Organization from an Orderly Universe (San Francisco: Berrett-Koehler Publishers, 1992).

17. P.M. Allen, M. Sanglier, G. Engelen, and F. Boon, " Towards a New Synthesis in the Modeling of Evolving Complex Systems," Environment and Planning B: Planning and Design, Volume 12, (1985), pp.

18. K. Evans, A. Schroeder and G. Wamsley, "Policy Subsystems and the New Physics," unpublished paper presented at Network Analysis and Innovations in Public Programs Conference, October 1, 1994; and Philip S. Kronenberg, "Survey of Chaos and Complexity Researchers on Planning and Public Policy," unpublished paper Virginia Tech Center for Public Administration and Policy, 1994.

19. Stephen Coleman, "Cycles and Chaos in Political Party Voting," Journal of Mathematical Sociology, Volume 18, (1993), pp. 47-64; Daniel S Geller, "The Impact of Political System Structure on Probability Patterns of Internal Disorder," American Journal of Political Science, Volume 31, (May 1987), p. 212-222.

20. Louise K. Comfort, "Self Organization in Complex Systems," Journal of Public Administration Research and Theory, Volume 4, No. 3, (July 1994) pp. 393-410; L. Douglas Kiel, Managing Chaos and Complexity in Government, (San Francisco: Jossey-Bass Publishers).

21. Gary Gemmill and Charles Smith, "A Dissipative Structure Model of Organization Transformation," Human Relations, Volume 38, (August 1985), p. 751-766; Kenneth D. Bailey, Sociology and the New Systems Theory: Toward A Theoretical Synthesis. (Albany, NY: State University of New York Press, 1994).

22. Estellie M. Smith, "Chaos in Fisheries Management," Maritime Anthropological Studies, Volume 3, No. 2, (1990), pp. 1-13.

23. Kiel, "Nonequilibrium Theory," p. 547.

24. Elinor Ostrom, Governing the Commons: The Evolution of Institutions for Collective Action, (Cambridge: Cambridge University Press, 1991) pp. 58-101.

25. Committee on Interior and Insular Affairs, United States Senate, (July 9 and 10, 1958). Hearings Before the Subcommittee on Irrigation and Reclamation. Eighty-fifth Congress, Second Session on S. 3648.

26. The Navajo agreed to the diversion of their water from the San Juan River to the Rio Grande River during the San Juan/Chama Diversion legislative process. The computed value of indian water diverted to the project was supposedly reasonably close to payment levels for the anticipated cost of capital for the NIIP.

27. Navajo Agricultural Products Industry, Annual Report For FY 1994. Farmington, New Mexico.

28. Senate hearings testimony, p. 49.

29. Ibid., p. 48.

30. NAPI board members are nominated by the Tribal Council, the elected representative governing body of the Navajo nation, and confirmed by the Economic Development Commission. It is important to understand that the Tribal Government, the Economic Development Commission and NAPI are fully autonomous policy making bodies within the Navajo Nation Decisionmaking authority for NIIP policy is vested in the tribal authorities. Since 1985 even the BIA's relationship with NIIP and NAPI has been

relegated strictly to responsibility for federal funding acquisition. The Navajo people rightly consider themselves to be in full policy making control of the project at this point. Source: Telephone interview February 27, 1994 with Carolyn M. Yazzie, Public Relations Coordinator, Navajo Agricultural Products Industry, Farmington, New Mexico.

31. Judith Eva Jacobsen, A Promise Made: The Navajo Indian Irrigation Project and Politics in the American West. (Ph. D. Dissertation, University of Colorado, 1989) p. 143.

32. Ibid., p. 137.

33. Ibid., p. 156.

34. Ibid., p. 147.

35. Dobuzinskis, "Modernist and Postmodernist Metaphors," p. 364.

36. Ilya Prigogine, " Time and Human Knowledge," Environment and Planning B: Planning and Design, Volume 12, (1985), pp. 5-20.

37. Ostrom, Governing the Commons, p. 101.

38. Philip W. Reno, Mother Earth, Father Sky and Economic Development: Navajo Resources and Their Use, (Albuquerque: University of New Mexico Press, 1988).

39. Kiel, "Nonequilibrium Theory," p. 546.

40. Jacobsen, A Promise Made, p. 150.

41. Ibid., p. 151.

42. Ibid., p. 162.

43. Personal Interview with Carolyn Yazzie, NAPI Public Relations Coordinator, February 27, 1995, Farmington, NM.

44. Kiel, "Nonequilibrium Theory," p. 549.

45. Idem.

46. Erich Jantsch, The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution. (New York: Pergamon Press, 1980).

47. Elinor Ostrom, quoted in Shui Yan Tang, "Institutional Arrangements and the Management of Common-pool Resources," Public Administration Review, Volume 51, No. 1, (January/February 1991) pp. 42-50.

48. For example, in Philip Kronenberg's 1994 survey of chaos and complexity researchers more than 200 respondents indicated interest in learning more about bringing nonequilibrium theories into their work. More than 80 were identified as active scholars, writers and researchers presently working with nonequilibrium theory applications in their own research.

49. Guy Engelen, "The Theory of Self-Organization and the Modelling of Complex Systems," European Journal of Operational Research, Volume 37, (October 1988), p. 44.

50. Kiel, "Nonequilibrium Theory," p. 548.